Reformulated Gasoline:
Cleaner Air on the Road to Nowhere

James S. Cannon

Starting January 1, 1995, nearly one-third of US motorists will find something different when they pull up at the gas pump: reformulated gasoline. This new variety of gasoline is designed to reduce the environmental impact of burning the fuel in 10 major metropolitan areas where air quality fails to meet the public health standards of the Clean Air Act of 1990, including the Washington-to-Boston corridor.

But turning to reformulated gasoline as the solution to our transportation fuel troubles is like rearranging the deck chairs on the Titanic — without noticing the direction the ship is headed. The passengers may be a little more comfortable, but who's preparing the lifeboats for the impending end of the voyage? Our ride on oil is almost up, and our lifeboats must be policies that invest now in the development and demonstration of alternative transportation fuels and new automotive technologies. We need policies that can lead us toward a sustainable transportation fuel economy.

By the early part of the next century, alternatives to oil are certain to play a major role in the global transportation economy. The most immediate arguments for abandoning oil are limited, dwindling reserves and the damage gasoline-powered vehicles inflict on human health and the environment. But fuel supply and the environment are only part of the energy equation. The economic cost of obtaining and using oil, plus the political and military costs of maintaining access to foreign oil supplies, have become increasingly untenable. Yet for the last two decades, business and government efforts to address the problems of using oil in transportation have focused primarily on reducing tailpipe emissions.

In 1975, the federal government mandated the use of catalytic converters to control vehicle pollution. But it has become clear that these controls do not adequately address the automotive pollution problem. As the government sought a better solution, the oil and automotive industries proposed to "reformulate" gasoline to make it cleaner. As of January 1995, Federal law requires gas stations in the 10 most heavily polluted urban areas to sell only cleaner "reformulated" gasoline.

Relying on this route merely solidifies our commitment to oil and fails to provide the essential ingredients for a

US transportation system that can serve not only our children, but their grandchildren. This route also fails to take into account the potential impact on US energy policy of a major international development: the expansion of automotive infrastructures in modernizing nations and the implications of this expansion for the United States.

After more than a century of rising energy consumption, global oil production is reaching its peak. In the United States, oil production has declined 24 percent since its peak in 1970. The world is at a crossroads: We must make the shift from a transportation infrastructure based on the production, distribution, and use of gasoline to one based on clean, renewable fuels and the vehicles that can run on them.

Oil production statistics highlight the short-sighted nature of policies that promote investment in reformulated gasoline over the development of alternative fuels that would lead us away from the finite and dwindling supply of oil.

Of all the currently available alternative fuels, natural gas offers by far the brightest immediate option for reducing harmful auto emissions and lessening our reliance on foreign energy resources. Tens of thousands of natural gas vehicles are on the road in the United States today, helping to improve air quality in urban areas. While natural gas is more abundant than oil and could greatly alleviate the pollution and supply problems associated with oil-derived fuels over the next few decades, it faces ultimate supply constraints. However, in stark contrast with reformulated gasoline, which lends nothing to the development of an alternative fuel infrastructure, natural gas can provide a technological link to the use of another gaseous fuel that may provide energy for centuries: nonpolluting, renewable hydrogen.

As shown in the demonstration vehicles built to date, hydrogen burned in internal combustion engines releases far lower levels of emissions than reformulated gasoline or, for that matter, any fossil fuel, including natural gas. But it is in high-efficiency fuel cell engines that hydrogen shows itself to greatest environmental advantage. Hydrogen fuel cell engines may well be able to power clean electric vehicles that could leapfrog technologically over the batteries that typically power electric cars today.

Despite the exciting prospects for hydrogen as a long-term solution to our global transportation energy problem, it is impossible to create a hydrogen-based transportation system overnight. Nor will a sustainable hydrogen-based fuel economy grow out of programs that prolong reliance on oil-derived fuels through the use of reformulated gasoline. However, research and development programs directed at optimizing use of clean-burning natural gas could provide the kind of infrastructure, fuel distribution, and fuel use systems needed to develop hydrogen as a fuel that may serve our needs tomorrow.

A sustainable energy system

The term "sustainable" has a specific meaning when used to describe an energy system. Sustainable energy must, first, rely on renewable resources, so that their use will not exhaust the supply. Second, the production and use of such renewable resources must not cause cumulative environmental damage that would, at some point, limit their use.

Solar energy could be the predominant energy resource of a sustainable energy system. But how can we tap the power of the sun — which every hour provides Earth with more energy than is released from a year's burning of coal, oil, and natural gas — to propel vehicles?

Table 1

History of World Oil Production — Impact of Exponential Growth

	Billion Barrels of Oil	Prior Cumulative Production (bill bbl)
pre-1900	0.54	0.00
1900-1920	6.47	0.54
1921-1940	27.24	7.01
1941-1960	73.39	34.25
1961-1980	266.45	107.64
1981-2000	445.23	374.09
2001-2020	1081.79	819.32
World Oil Reserves – 1992	1092.40	

The answer is both fantastic and full of common sense: use solar energy to produce a clean fuel that's easy to move around. Hydrogen, the most abundant element in the universe, is a pollution-free fuel that can power automotive engines. Solar energy, such as the rays of the sun or wind power, can split the water molecule into its constituent parts — oxygen and hydrogen. Thus, solar-derived hydrogen may be the optimum fuel to replace gasoline in a not-so-distant sustainable transportation future.

The rise and decline of the oil age

The world is in the middle of the second major energy transition in human history. The first major energy transition began about two centuries ago, when the advent of coal-burning ended thousands of years of total reliance on renewable resources, mostly food and wood, in favor of a fossil fuel. The transition to fossil fuels (coal, oil, and natural gas) did not even begin to affect personal transportation until 1859, when the discovery of oil — the second fossil fuel to be used widely — spurred the gradual replacement of horses with gasoline-powered automobiles as the most common form of personal transportation in the industrialized world. More than 99 percent of the 190 million vehicles in the United States are powered by oil-derived fuels.

As the world approaches the peak of fossil fuel production, it is on the verge of the second energy transition, a move away from fossil fuels and back to renewable sources of energy. This move is made inevitable by the approaching exhaustion of oil reserves. As shown in Table 1, during every 20-year period in this century, the world has produced more oil than has been produced in all previous history. This pattern is likely to continue through at least 2020, even if the growth rate falls to a mere 2 percent annually (far below the 6 percent annual growth rate experienced in this century). The projected production of oil between 2001 and 2020 almost equals total world oil reserves in 1992. Although new oil deposits may be found, most readily-exploitable oil reserves have been identified. Thus, while oil may not disappear from use in the immediate future, its cost may skyrocket and its availability may be drastically reduced in the next few decades.

Oil production statistics highlight the short-sighted nature of policies that promote investment in reformulated gasoline over the development of alternative fuels that would lead us away from the finite and dwindling supply of oil. Industry expects reformulated gasoline to cost between $0.04 and $0.10 more per gallon at the pump because of adjustments to oil refining equipment, more refining, more work, and more byproducts sent to disposal. But perhaps more significantly, government mandates to use reformulated gasoline may entail an opportunity cost. Knowing that we are doing "something" about the automotive pollution problem may temper the sense of public urgency needed to drive policies that consider the broader picture of transportation energy.

A policy promoting reformulated gasoline is essentially a stop-gap measure — one that fails to create incentives to develop fuels that will reduce reliance on oil.

Reformulated gasoline: A stop-gap measure

More than one-third of the US population, some 85 million people, lives in urban areas where air quality violates federal public health standards, largely because of automotive pollutants. Gasoline and diesel-fueled cars, trucks, and buses produce half of all air pollution in the United States, emitting 66 percent of airborne carbon monoxide, 31 percent of smog-forming hydrocarbons, and 43 percent of lung-damaging nitrogen oxides. Reformulated gasoline offers a way to reduce a variety of gasoline emissions without overturning the status quo — that is, without developing alternative fuel technologies to replace oil-derived fuels and the internal combustion engine.

The oil and automotive industries first proposed the establishment of a reformulated gasoline program during the 1990 debate over amendments to the Clean Air Act. The industries' goal was to knock out provisions of the bill requiring the use of alternative transportation fuels, such as natural gas, ethanol, or methanol. Arguing that promotion of alternative fuels was unnecessary because gasoline could be made to burn more cleanly by reformulating chemicals in the fuel, the oil and automotive industries convinced Congress to include a reformulated gasoline program in the bill. However, Congress did not abandon promotion of alternative fuels in some applications.

The Clean Air Act Amendments of 1990 specify that, beginning January 1, 1995, all gasoline sold in areas classified by the Environmental Protection Agency as suffering from "extreme" or "severe" ozone pollution problems must be reformulated. Ten major metropolitan areas currently fit into this classification, including most of the Boston-New York-Washington, DC, corridor. Refiners, distributors, and retailers in the regulated areas, which cover about 30 percent of the national gasoline market, are all gearing up to start delivering and pumping the new, more costly fuel. States with less extreme ozone pollution also may petition EPA for inclusion in the program.

Using the composition of the average grade of gasoline on the market in 1990 as the standard, the definition of "reformulated" includes these key factors:

- a 15 percent reduction in toxic chemicals, including volatile organic compounds
- a maximum of 1 percent of the carcinogen benzene (a 50 percent reduction) and a maximum of 25 percent for aromatic hydrocarbons (compared with 40 percent previously)
- a minimum content of 2 percent oxygen, by weight, to promote cleaner combustion – especially to reduce carbon monoxide emissions.

Since late 1992, federal law has required the wintertime sale of fuels with a minimum oxygen content, called "oxygenated fuels," in about 40 metropolitan areas where cold temperatures lead to increased carbon monoxide levels. An oxygenate derived from methanol, called methyl tertiary butyl ether (MTBE), accounts for the bulk of this market and is likely to be most in demand for the reformulated gasoline program as well. Ethanol accounts for most of the remainder of the oxygenated fuels market.

When used in conventional automobiles, reformulated gasoline can cut tailpipe emissions of the major pollutants regulated under the Clean Air Act — carbon monoxide, hydrocarbons, and nitrogen oxides — by 10-20 percent compared with gasoline. But this pales in contrast with a 40-to-95 percent reduction of those pollutants, vis-a-vis gasoline, when an engine runs on natural gas.

The gasoline and automobile industries assert that combining reformulated gasoline with more advanced pollution control devices will enable them to meet the more stringent hydrocarbon levels set by California's Low Emission Vehicle standard, and perhaps even the Ultra-Low Emission Vehicle Standard, although no gasoline engines have been certified at the ultra-low levels to date. Vehicles powered by reformulated gasoline will never be able to meet California's strictest standard, the Zero Emission Vehicle, which is to account for 2 percent of the state's auto sales in 1998, rising to 10 percent by 2003. Only electric vehicles meet this standard today. Several Northeastern states that are members of the Ozone Transport Commission have moved to adopt California's emission program, including the zero emission standard.

Even if reformulated gasoline combined with pollution controls is able to meet high goals for reducing tailpipe emissions, a policy promoting this strategy is essentially a stop-gap measure — one that fails to create incentives to develop fuels that will reduce reliance on oil. Reformulating gasoline does nothing to improve gasoline's energy efficiency and thus nothing to extend the supply of oil from which it is refined. Burning gasoline in cars is one of the most wasteful uses of this resource. In fact, only 12 percent of the energy expended in the production, distribution, and use of gasoline reaches the wheels of the vehicle, whether the gasoline is reformulated or not. Use of reformulated gasoline also fails to enhance energy security, to boost US competitiveness in international markets, or to pave the way for the inevitable transition to a transportation economy based on renewable resources. Nor does it help the US auto industry improve its competitiveness in rapidly changing world markets.

Expanding worldwide automotive markets

The number of automobiles in the world has doubled approximately once a decade during this century. The US market for automobiles is more or less saturated: there is one car for every 1.7 people. But markets in the developing world are wide open. In China, a country now experiencing extremely rapid economic growth, 1.7 million cars serve a population of roughly 1.2 billion, or one car per 652 people. In India, people outnumber cars by 354 to 1; in Africa, the ratio is 71 to 1.

Initiatives to boost auto production in modernizing countries around the globe may affect US energy policy in two ways. First, rising auto production undoubtedly will put additional strain on already diminishing supplies of oil, creating a fresh round of crises in the availability of oil in the United States.

Second, and perhaps more important, countries now developing an auto infrastructure face conditions that contrast sharply with those of the United States at the turn of the last century. Back then, oil was cheap and plentiful, and concern over the environmental impact of burning gasoline was practically nonexistent. Today, countries that hope to expand their use of automobiles face plummeting supplies of oil and heightened concerns over vehicle emissions. To avoid the very problems posed by the gasoline-powered internal combustion engine, it makes sense for countries now building a transportation system from the ground up to look to alternative sources of fuel and to alternative engine technologies. Leading-edge development of renewable energy technologies by Germany and Japan — countries not particularly well-endowed with renewable resources — reflects the belief that markets for renewable energy products will emerge in the developing world. If the United States aims to compete in the international auto and energy markets of the future, it must be developing advanced technologies now that will lead us toward clean, renewable fuels in automotive engines. US reliance on reformulated gasoline and on the century-old technology for burning it only postpones our development of alternative transportation technologies that will be in demand in the decades to come. Natural gas vehicles could meet that demand today, while in the longer term hydrogen produced from renewable resources could become the fuel of choice for a sustainable energy economy.

Challenges for a transportation system

The challenges facing any move to alternative fuels fall into three categories:

- Fuel production and distribution
- Fuel use, including storage and refueling
- Engine technology, including any mechanism that propels the vehicle

Along the path from a natural resource to the eventual use of fuel in an engine, called an energy pathway, there are many choices. These include: how to harness the energy in the resource (for example, mining coal, drilling for oil, installing solar panels); whether the resource is transformed into an "energy carrier," a different form that can be easily moved about (for example, electricity is distinct from the coal used to generate it); and how the fuel is used in an automotive engine to release its energy (for example, combustion, batteries, or fuel cells).

The viability of a given transportation energy pathway is limited by a number of considerations: supply, environmental impact, cost, safety, energy efficiency, and vehicle operating restrictions such as weight and volume of the fuel storage system, ease of refueling, and durability. Despite its disadvantage in terms of supply and lackluster environmental improvement, reformulated gasoline offers the advantage of a convenient fuel storage and refueling system.

Natural gas vehicles are safer to operate than gasoline-powered vehicles because natural gas rises and disperses quickly in air — significantly reducing the risk of fire in crashes.

The gaseous state of natural gas and hydrogen at normal atmospheric pressure makes them more difficult to handle. But burning gasoline in an internal combustion engine is not necessarily safer than using gaseous fuels to power a car.

Each year, fuel leaking from flimsy gasoline tanks ignites in accidents that cause more than 1,700 deaths and another 7,000 injuries in the United States alone. In contrast, a 1992 national survey published by the American Gas Association found that the injury rate in accidents involving natural gas vehicles, measured in terms of miles traveled, was 37 percent lower than the rate for gasoline vehicles. The study also found no deaths involving natural gas vehicle use, based on 278.3 million miles traveled. Natural gas vehicles are safer to operate than gasoline-powered vehicles because natural gas rises and disperses quickly in air — significantly reducing the risk of fire in crashes.

The trend toward cleaner, more powerful fuels

Since the discovery of coal, the world has been moving toward cleaner fuels that contain less carbon and more hydrogen, and, as a result, deliver more energy per pound of fuel. (Although people think of "carbon-based fuels" as providing high energy levels, it is the hydrogen in such fuels that, when burned, provides much of the energy.) As shown in Table 2, coal was a "better" fuel than wood because, with hydrogen constituting 50 percent of its atoms, it releases more energy when burned. Similarly, oil supplanted coal as the world's primary energy resource because it contains even more energy per pound.

Burning carbon does release energy, but one of carbon's main roles is to anchor hydrogen, the lightest element, in solids, liquids, and gases that can be tapped as energy resources. More carbon means a stronger anchor. Thus coal, with a high carbon content, is a solid; oil is a liquid; and natural gas, with only one carbon atom in its structure, is a gas. Vehicles that burn gasoline and diesel fuel in the United States account for 31 percent of carbon dioxide emissions, which are considered the principal cause of global warming. Far from reducing these emissions, reformulating the chemistry of gasoline may actually lead to increased production of carbon dioxide during combustion.

Table 2

Fuel Characteristics: Effect of Carbon and Hydrogen Concentrations

Fuel Type	% Carbon (mole*)	% Hydrogen (mole)	Combustion Energy (Btu/lb)	Air Pollution (lb/million Btu) Particulates	Carbon Dioxide
Dry Wood	95%	5%	4,504	5.22	775
Coal	50%	50%	10,000	5.00	240
Oil	33%	67%	18,500	0.18	162
Natural Gas	20%	80%	21,250	<0.01	117
Hydrogen	0%	100%	62,500	0.00	0

** a quantitative measurement of a chemical based on its atomic weight.*

Pure hydrogen contains no carbon. Compared with oil, hydrogen packs 3.3 times more energy into each pound of fuel. Another virtue of hydrogen's carbon-less state is its clean combustion: burning hydrogen releases no particulate emissions, and it releases no carbon dioxide.

Natural gas: The cleanest fossil fuel

Natural gas, the cleanest and most energy-dense of the fossil fuels, is an immediate, viable option for vehicles. Unlike oil, which is in short supply in the United States, natural gas supplies in the United States are still plentiful. Since 1986, US natural gas production has increased 4 percent, while oil production has declined 13 percent. Natural gas is also cheaper than gasoline, selling wholesale at half the price.

When burned in a conventional internal combustion engine, natural gas is clearly superior to reformulated gasoline on the basis of environmental emissions, supply, cost, energy security, and safety. These factors have helped make natural gas an attractive option for operators of fleet vehicles, such as United Parcel Service and the US Postal Service, and for operators of urban buses in more than 20 cities from New York to Los Angeles. Operators of fleet vehicles are using more than 40,000 cars, vans, and buses powered by natural gas. Natural gas vehicles offer advantages over another currently available alternative transportation option: the battery-powered electric vehicle. Natural gas vehicles enjoy greater driving ranges and faster refueling speeds than electrics.

However, the infrastructure for use of natural gas in passenger vehicles is still sparse: there are only about 1,000 natural gas refueling stations, compared with 150,000 gasoline stations. As a result, the market for natural gas vehicles is largely restricted to fleet operators, who can build or gain access to refueling facilities.

As described in INFORM's report *Paving the Way to Natural Gas Vehicles* (1993), there has been rapid progress in research and development efforts devoted to engines that burn natural gas. But the commercialization of these vehicles and the establishment of a refueling infrastructure to use them are growing at a slower pace. Governments at the federal and state levels are using such incentives as mandates, grants, financing programs, and preferential tax treatment to promote greater use of clean-burning natural gas vehicles. But it is clear that far more could be done to promote these vehicles.

Natural gas is the bridge that could link currently available automotive technology to the use of hydrogen over the next few decades.

Despite its tremendous advantages, natural gas is not the optimum fuel for a sustainable energy future — that is, a future based on renewable resources and a pollution-free fuel. Like reformulated gasoline, natural gas is a fuel with a finite supply. And while natural gas emits less of the major air pollutants regulated under the Clean Air Act than does gasoline, discharges of carbon dioxide are still significant when natural gas is burned. Natural gas vehicles also emit an unregulated pollutant, methane, which likewise is implicated in global warming.

Natural gas vehicles can play an important and immediate role both in reducing air pollution in the nation's smog-filled cities and in lessening reliance on foreign energy resources. And they can play a crucial long-term role. The establishment of a natural gas fuel economy now could ease the transition to a hydrogen fuel economy in the future.

Natural gas links to hydrogen

If reformulated gasoline is the dead-end street of the transportation infrastructure, natural gas is the bridge that could link currently available automotive technology to the use of hydrogen over the next few decades. As a gaseous fuel, hydrogen faces many of the same obstacles that limit the use of natural gas in transportation markets. There may be a synergy between the two fuels if the infrastructure and technology to use gaseous fuels in transportation first are established for natural gas, a readily available fuel. This infrastructure and technology then could be adapted for hydrogen at the point when advanced production and engine technologies make it a viable fuel for vehicles.

The technologies to store natural gas and hydrogen in vehicles and to burn these fuels in internal combustion engines are often very similar. Natural gas mixtures containing up to 20 percent hydrogen can burn in a natural gas combustion engine without making adjustments to the engine. Storing both natural gas and hydrogen requires compression systems to ensure that these light, gaseous fuels are packed densely enough to provide sufficient energy for the engine.

With current compression technologies, natural gas still takes up four times as much space as a comparable gasoline system, and compressed hydrogen takes up nine times as much space. Converting natural gas and hydrogen into liquids offers greater densities of energy per unit of volume, thereby reducing the space requirements. But the super-cold temperatures needed to maintain these gases in a liquid state present a costly technical challenge. Because of these similarities between the two fuels, technological advances in natural gas vehicle development are likely to benefit hydrogen vehicle development and vice versa.

There are also links between the production and distribution of natural gas and the production and distribution of hydrogen. Nearly all of the hydrogen produced commercially in the world today is manufactured from natural gas. Until technologies capable of producing hydrogen from renewable resources become cost-effective, natural gas can provide the feedstock for hydrogen production. Similarly, the 1.3 million miles of natural gas pipeline in the United States could be used to transport hydrogen, in some cases with only minor modification. This pipeline system could provide the backbone of a future hydrogen distribution system.

Like natural gas, hydrogen also disperses quickly into the air, reducing the risk of fire in accidents. However, hydrogen use in vehicles raises other safety concerns, particularly regarding its low ignition temperature and its ability to burn in a wide range of concentrations with air. Technological solutions to these concerns exist, but additional research and development programs are needed to bring hydrogen technology up to the performance and safety level of gasoline technology.

Two pathways for hydrogen use in vehicles

Hydrogen may be used as an automobile fuel through two technological paths:

- Internal combustion engines connected mechanically to the wheels of conventional vehicles
- Fuel cell engines connected electronically to the wheels of electric-powered vehicles

While hydrogen is a clean-burning fuel, its real advantages become apparent when it is used in fuel cells, which are cleaner and more energy-efficient than combustion engines. As vehicles propelled by hydrogen produced from solar energy enter the market, these vehicles will totally eliminate air pollution, including pollution from fuel production and distribution.

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Internal combustion engine technology is very well developed, having powered most of the world's automobiles for the last century. These engines can be adapted to burn pure hydrogen or fuel mixtures containing hydrogen. But hydrogen's use in vehicles has been held back by the fuel's high cost and by the high weight and space requirements for onboard hydrogen storage. Current research and development efforts indicate that these hurdles can be lowered to tolerable levels, and that hydrogen holds promise as an automotive fuel in conventional engines.

In a fuel cell, hydrogen and oxygen merge without combustion, releasing energy as electricity and leaving a trail of water vapor as their only byproduct. Fuel cells are cleaner than combustion engines for two reasons: 1) they do not require lubricating oil, thereby eliminating the trace amount of pollutants produced in combustion engines; and 2) in most cases they do not generate temperatures high enough to cause nitrogen and oxygen in the air to fuse, thereby avoiding the formation of the nitrogen oxides associated with combustion.

It is an inescapable fact that, from a supply standpoint, gasoline, however reformulated, is not a long-term fuel option.

Fuel cell engines are also two to three times more efficient than hydrogen combustion engines in delivering the energy in the fuel to the wheels of the vehicle. Consequently, much less fuel is needed to power a vehicle, which helps lower fuel costs and makes it possible to reduce the weight and volume of storage systems.

The United States developed the world's most advanced fuel cell technology for the space program in the 1960s, but the world's first fuel-cell-powered on-road vehicle did not make its debut until June 1993, when Ballard Power Systems demonstrated its fuel cell bus in Vancouver, British Columbia. US and European fuel-cell-powered cars have followed. But significant technological and economic problems need to be solved before any electric vehicle, including those powered by batteries, emerges as a viable alternative to combustion-engine-powered vehicles.

Both hydrogen combustion engines and fuel cell engines can be combined with electrical storage systems, such as batteries, and used in a third type of vehicle: the hydrogen electric hybrid. Hybrid vehicles may prove to be lighter, smaller, and more versatile than vehicles based solely on either engines or electrical storage systems. For example, adding onboard electrical generation, in the form of a fuel cell, to a battery-powered vehicle allows a reduction in size of the battery pack. Hybrids can also increase vehicle performance. For example, internal combustion engines in electric hybrid vehicles can be engineered to operate at a steady speed, doubling engine efficiencies. The battery provides extra power for bursts of speed or hill-climbing, while excess power generated while the vehicle is idling or running at slow speeds can be used to recharge the battery. Demonstration projects for both fuel cell and combustion engine hybrids are currently underway in the United States.

Fuel cells: Superior to batteries for powering electric vehicles

Given that electric vehicles are, to date, the cleanest cars on the road, the next question is: What type of electric vehicle is the most viable? The most prevalent type of electric car under development is powered by batteries, which store energy in the form of chemicals. When the chemicals are used up, the battery must be recharged with electricity from an outside source to reverse the chemical reactions and restore the reactants. Although electric power plants tend to emit less pollution than tailpipes, plugging batteries into power lines still "shifts" some pollution to another source. Eventually, when the battery is discarded, its toxicity poses a disposal problem.

In contrast, hydrogen fuel cell engines actually generate electricity, rather than simply storing it. As long as hydrogen and oxygen are supplied to fuel cells, they can produce electricity indefinitely. By offering advantages in three critical areas — refueling, weight, and volume — fuel cells may overcome the underlying reason for the failure to commercialize electric vehicles: their limited driving range.

In today's battery-powered electric vehicles, recharging typically takes 6-10 hours. Refueling technologies under development for hydrogen fuel cells are much faster, although they still take 10-15 minutes per car refueling.

With regard to weight, a system using a lead-acid battery, the most common battery on the market, weighs 45 times more than a gasoline tank offering the same driving range. Depending on the type of hydrogen fuel cell used, a fuel cell system may weigh the same as a gasoline system for an equivalent driving range, or up to four times that weight — still slightly less than the weight of the most advanced batteries projected by the battery industry.

Similarly, lead-acid batteries take up 17 times more space than an equivalent gasoline tank, while fuel cells take up from 1.2 to 4 times as much space — still less than the battery industry's projections for development of smaller batteries.

Natural gas and hydrogen in US energy policy

Natural gas vehicles account for about half of the federal government's $20 million annual purchasing budget for alternative fuel vehicles, with the remainder taken up by methanol, liquefied petroleum gas, and electric vehicles. Government committment to expanding the nation's fleet of natural gas vehicles could have the spillover effect of increasing public access to refueling facilities, and thus increasing personal use of natural gas vehicles. A broader infrastructure for natural gas use in vehicles could, in turn, facilitate an eventual shift to hydrogen as a transportation fuel.

In contrast with natural gas use, hydrogen's use in vehicles requires extensive research and development before purchasing can become an option. Federal funding for hydrogen research and development activities grew tenfold from 1990 to 1994, but the $30 million annual expenditures remain only a little more than one-tenth of 1 percent of the Department of Energy's $18 billion annual budget.

Most federally sponsored hydrogen research and development occurs within the National Hydrogen Program and the National Fuel Cell in Transportation Program. The first seeks to boost levels of hydrogen use in the United States to 5 percent of total energy use by 2010 and to more than 11 percent by 2030. The National Hydrogen Program incorporates research and development with technology demonstrations.

The National Fuel Cell in Transportation Program focuses on developing a fuel cell suitable for powering an electric vehicle and developing a hydrogen storage system suitable for such a vehicle. The program includes fuel cell engine development, basic research and development of energy storage systems, and supporting analyses of safety and environmental concerns.

Most US government-sponsored alternative fuels and transportation research, however, is not specifically focused on hydrogen, although it may include hydrogen technology incidentally. For example, the $2 billion cooperative effort between the federal government and the Big Three auto manufacturers known as the Clean Car Initiative, or the Partnership for a New Generation of Vehicle, seeks to develop a prototype car that runs 80 miles to the gallon. Given their high fuel efficiency, hydrogen fuel cells may emerge as a preferred technology through this program. However, most industry research efforts are still focused on improving the performance of conventional combustion engine and oil-derived fuel technologies.

A commitment to change

When faced with the daunting task of years of research into alternative fuel technologies and the prospect of building a new passenger vehicle infrastructure from scratch, it may seem logical for the oil and automotive industries to promote the continued reformulation and use of gasoline in internal combustion engines. But it is an inescapable fact that, from a supply standpoint, gasoline, however reformulated, is not a long-term fuel option. It is also clear that internal combustion engines, even those fitted with pollution control devices, do not match the zero-emission standards of electric vehicles.

The people of the industrialized world expect a high level of convenience, comfort, and communication. Other nations with growing economies are seeking a similar quality of life on a level made possible by modern technology and transportation systems. Whether maintaining or expanding their use of vehicles, all societies will need to find long-term alternatives to conventional fuels and fuel systems.

As the world moves along the inevitable path to clean, renewable alternative energy resources, the United States has the opportunity to become a leader in the technology to use those resources. By choosing energy policies that go beyond simply curbing environmental emissions, the United States can prepare itself to meet the end of the oil age with an environmentally and economically sustainable energy infrastructure. Increased use of natural gas vehicles today offers the best "bridge" for the transition from fossil fuels to the eventual use of hydrogen in vehicles. Policies that facilitate this transition could also improve the competitiveness of US industries in global energy and automotive markets. Taken together, the rationale for developing a new fuel economy based on hydrogen should be one that policymakers, business leaders, environmentalists, and taxpayers can all appreciate.

About the Author

James S. Cannon, a Senior Fellow at INFORM, is an internationally recognized expert on energy development, environmental protection, and related public policy issues. He is the author of *Drive for Clean Air* (1989), the highly influential study of natural gas and methanol as alternative fuels, and *Paving the Way to Natural Gas Vehicles* (1993), which identifies the actions necessary for expanding use of natural gas in transportation. His forthcoming book, to be published by INFORM in the spring of 1995, investigates the viability of solar-generated hydrogen as the basis of a sustainable transportation fuel economy in the 21st century.

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Paving the Way to Natural Gas Vehicles (James S. Cannon) 1993, 192 pp., $25.

Stirring Up Innovation: Environmental Improvements in Paints and Adhesives (John Young, Linda Ambrose, Lois Lobo) 1994, 128 pp., $25.

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